GEOLOGIC MAP OF THE WEST SIDE OF THE MOON

By
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DESCRIPTION OF MAP UNITS

Cc CRATER MATERIAL—Rim, wall, and floor deposits of craters with sharp prominent rims, and circular to polygonal outlines; larger craters have rough concentrically structured inner rim deposits, smooth radially lineated outer rim deposits, and arrays of secondary craters; rays visible on full-Moon photographs. *Interpretation:* Impact crater materials

CEd DOME MATERIAL—Single occurrence at east edge of map (Hansteen α). Steep-sided bulbous dome with hackly surface, very high albedo; small linear depressions at crest; apparently superposed on adjacent mare. *Interpretation:* Volcanic dome formed by viscous eruptive rocks; linear crestal depressions may be vents. Similar to but somewhat more degraded than Gruithuisen domes (Scott and Eggleton, 1973)

Ec CRATER MATERIAL—Rim, wall, and floor materials of topographically sharp fresh-appearing craters; similar to craters of Copernican age but slightly more subdued and rayless on full-Moon photographs. *Interpretation:* Impact crater materials

EIm MARE MATERIAL—Forms smooth flat surfaces having low to very low albedo and low crater density in Oceanus Procellarum, Orientale, Grimaldi, and some craters. Spectral reflectance measurements (Soderblom, in preparation) indicate mare ranges from red to blue in color. Rays and Eratosthenian craters superposed, upper Imbrian and older craters embayed. Numerous ridges, mostly trending NW and NE. Lunar Orbiter IV photographs suggest that darker mare may have lower density of craters than lighter mare patches (McCauley, 1973; Scott and Eggleton, 1973). Zond 8 photographs provide excellent albedo contrast between mare and plains material (unit Ip) throughout most of map region. Discrimination difficult between mare and dark mantling material. *Interpretation:* Basalt flows. Albedo variations may be related to age color variations probably indicate changes in composition

EIph HILLY PLATEAU MATERIAL—Dome, cone, and dark mantle complexes; positive forms include: smooth low domes; bulbous, steep, or flat-topped domes with ramparts around summits; associated dark planar deposits that stand above general level of Oceanus Procellarum. Includes Marius Hills, Rümker Hills, and Aristarchus Plateau that have been mapped together for convenience. *Interpretation:* Volcanic constructs, flows, and pyroclastic materials (Moore, 1965; Wilhelms and McCauley, 1971; Scott and Eggleton, 1973)

Ic_2 CRATER MATERIALS—Similar to crater material of Eratosthenian age but more subdued; superposed on all formations of Orientale Group. *Interpretation:* Impact crater materials; some of smaller size may be secondary craters formed by high-angle ejecta

Ip PLAINS MATERIAL—Smooth flat to undulatory terrain of intermediate albedo; occurs mostly in topographic lows and crater floors of Imbrian and older age but also as small pools at different elevations; locally gradational with outer facies of Hevelius Formation but has ponded appearance and seems to embay or bury grooves and lineaments of the Hevelius. *Interpretation:* Multiple origins; some is ejecta from Orientale basin and large impact craters filling low areas; includes shock-melted rocks as well as volcanic materials. Ambiguity as to origin precludes inclusion in Orientale Group

ORIENTALE GROUP—Includes Maunder, Montes Rook, and Hevelius Formations

Iom MAUNDER FORMATION—Occurs as smooth to rolling, intensely fractured plains, broad linear ridges, and smooth equidimensional domes. Restricted to central part of Orientale basin within Montes Rook ring. Fractures, including grabens and rilles, show crude concentric and radial patterns; these structures are covered by and predate mare material. Scattered small smooth hills of knobby facies of Montes Rook Formation locally appear to protrude through unit. *Interpretation:* Probably mostly impact melt. Scattered small knobs may be fallback. Ridges and domes are original floor material compressionally modified by inward movement during last stages of basin formation. Fractures and faults caused by isostatic uplift of basin floor mostly prior to mare flooding. Some may be result of contraction during cooling

MONTES ROOK FORMATION—Divisible into a massif and a knobby facies

Iorm Massif facies —Large rectilinear to equidimensional massifs ranging from about 5 km to 100 km in length and several kilometers high; forms disconnected segments that mark the second and third rings of Orientale basin. Surfaces of individual blocks grade from smooth to knobby where they appear to be overlain by knobby facies of the Montes Rook Formation (unit Iork). Individual blocks separated by radial troughs. Some blocks appear to be rotated or displaced laterally from ring pattern. Shapes of massifs appear largely controlled by regional structure (lunar grid). Massifs most extensively developed in southwest quadrant of basin where ring structures are difficult to distinguish. *Interpretation:* Structurally uplifted prebasin bedrock thickly veneered with late arriving ejecta blocks and finer debris. Ring formed by massif facies marks approximate extent of original crater formed by impact; innermost ring of massifs probably represents central peak ring also veneered by ejecta

Iork Knobby facies—Knobby, hummocky, smooth, rolling, disordered appearing materials with irregular grooves and depressions between individual knobs. Knobs are up to about 5 km across. In places unit is weakly lineated in radial directions. Generally confined to region between Montes Cordillera scarp and Montes Rook. Locally gradational with lineated inner facies of Hevelius Formation. Large patches lie outside Montes Cordillera scarp. Contains vague circular outlines as much as 50 km in diameter. *Interpretation:* Uppermost part of overturned flap of ejecta sequence at Orientale. Overlies and almost completely buries earlier deposited inner facies of Hevelius Formation. Knobs represent coherent material quarried from deep within transient cavity. As these materials were last to leave the crater, they had considerably less radial velocity (Gault and others, 1968) than earlier ejecta units in Orientale group, thus accounting for their disordered appearance. Thickest part of ejecta sequence; upper layers not mixed with materials external to the transient cavity. Remnants of buried prebasin craters visible

HEVELIUS FORMATION—Divisible into an inner, transverse, outer, and a secondary crater facies

Iohi Inner facies—curvilinear to swirly ridges and troughs mostly radial and sub-radial to basin; contains lobes and tongues; locally ropy in appearance. Ridges up to tens of kilometers wide and hundreds of kilometers long; heights may exceed 1,000 m. Innermost boundary generally coincident with Montes Cordillera scarp where contacts are mostly gradational with knobby facies of Montes Rook Formation (unit

Iork). On north and west sides of basin is overlapped by knobby facies; in some places unit occurs within Montes Cordillera scarp. Vaguely expressed concentric wavy ridges up to 100 km long present outside scarp (concentric facies of Moore and others, 1974). Numerous primary and secondary ghost (buried) craters present. These become more pronounced and textures more swirly near boundary with outer facies (unit Ioho). *Interpretation:* Continuous part of Orientale ejecta blanket emplaced during outward flow of hot, turbulent, mobile materials. Intense secondary cratering and gouging has also contributed to overall texture of unit and to mixing of internal ejecta with prebasin materials outside scarp

Ioht Transverse facies—Closely spaced arcuate ridges and troughs at base of distal walls of prebasin craters and in elongate low areas radial to basin; mostly between 300 and 400 km from Montes Cordillera scarp. Best seen around east side of basin where viewing angles and sun angles of Lunar Orbiter photographs were optimal. Originally termed deceleration dunes (McCauley, 1968a). *Interpretation:* Ejecta of Orientale basin accumulated against or within topographic barriers to flow. Wavelike ridges and troughs related to yield strength and flow characteristics of viscous material and possibly to local relief of substrate

Ioho Outer facies—Variable characteristics; includes swirly, lineated, hummocky, and smooth materials. Laterally continuous with inner facies of Hevelius (unit Iohi) but difficult to define along western part of basin where photography poor. Intergrades in places with plains material (unit Ip) that forms ill-defined annulus around basin. Outermost boundary with prebasin terra (unit INt) indistinct and approximately located. Contains numerous fresh-appearing secondary craters (unit Iohs); prebasin craters locally protrude through unit. *Interpretation:* Thin and discontinuous part of Orientale basin's ejecta blanket. Many secondary craters and prebasin craters not completely buried. Closely spaced, sharp, swirly ridges occur where material flowed through preexisting topographic gaps

Iohs Secondary crater facies—Overlapping crater chains and clusters radial and peripheral to the basin. Individual craters as much as 30 km across form chains several hundred kilometers long. More abundant and larger on west side of basin than on east. Only most prominent examples, mostly superposed on outer facies of Hevelius Formation, mapped. Numerous elongate chains and grooves within inner facies of Hevelius have degraded rims and outlines. *Interpretation:* Secondary impact craters formed by ejecta from Orientale event. Chains and grooves within inner facies of Hevelius buried by later arriving ejecta

Ic_1 CRATER MATERIAL—Moderately subdued craters partly buried in places by materials of Orientale Group. *Interpretation:* Pre-Orientale impact material. Some may be secondary craters from Orientale event

If FRA MAURO FORMATION—Only in north-central part of map area; forms lineated to slightly swirly material grading southwesterly into gently hummocky to smooth slightly rolling terrain. Lineations subradial to Imbrium basin. *Interpretation:* Ejecta from Imbrium basin mixed with materials of substrate

INt TERRA MATERIAL (Undivided)—Gently rolling terrain with numerous craters and indistinct depressions. Intergrades with rim materials of older craters and, in places, with Hevelius Formation. *Interpretation:* Interlayered breccias, shocked rocks, and glasses derived from long period (Nectarian to Imbrian) of meteoroid bombardment of lunar crust, including formation of Orientale basin

Nhb HERTZSPRUNG BASIN MATERIAL—Smooth rolling with faint lineations directed toward Hertzsprung basin; only recognized south of basin where lineations distinguish it from terra material (unit INt). Subdued; buries or partly buries craters of Nectarian age and older including unit Nhsc, early Imbrian and younger crater materials superposed. Boundaries very indistinct; viewing and lighting angles of photographs poor. *Interpretation:* Ejecta from Hertzsprung basin

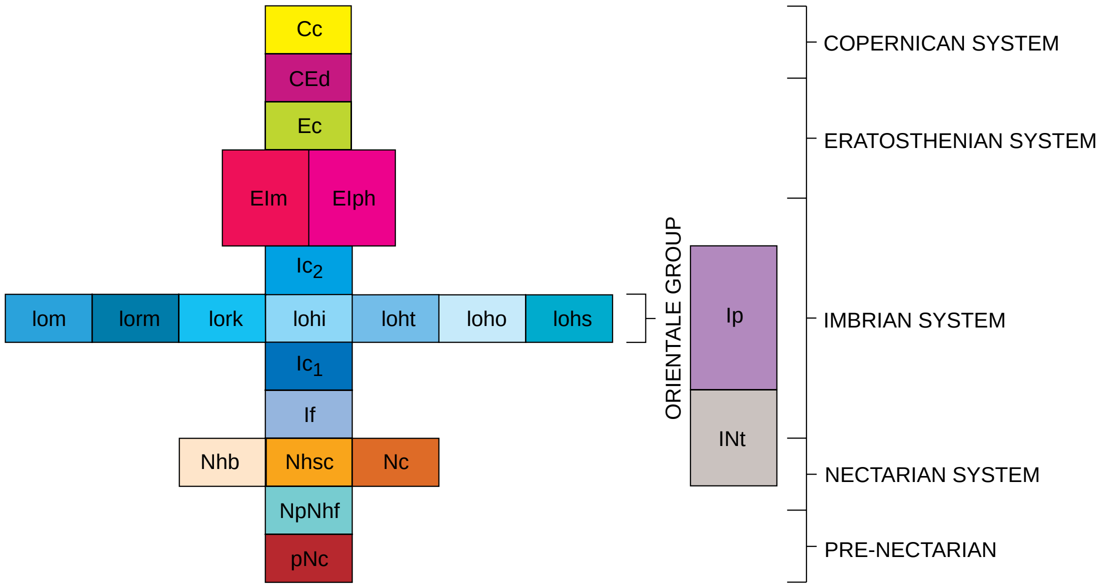
Nhsc HERTZSPRUNG SECONDARY CRATER MATERIAL—Forms elongate, shallow, highly subdued craters with long axes directed toward Hertzsprung Some partly filled by plains material (unit Ip). *Interpretation:* Secondary craters from Hertzsprung event

Nc CRATER MATERIAL—Subdued rim and wall deposits, terra or plains materials mostly cover original crater floors but only mapped in larger craters. *Interpretation:* Impact craters

NpNhf HILLY AND FURROWED MATERIAL—At east edge of map area. Gently rolling moderately cratered terrain with numerous small smooth hills, many slightly elongated; numerous small irregular depressions or furrows. *Interpretation:* Origin enigmatic but has some resemblance to knobby facies of Montes Rook Formation and might be ejecta from nearby Humorum basin

pNc CRATER MATERIAL—Highly subdued; crater outlines generally irregular or incomplete. Craters partly filled by younger materials; rims merge with adjacent terrain; numerous superposed craters. *Interpretation:* Most are impact craters

CORRELATION OF MAP UNITS



Contact

Mare ridge

Rille

Fault—Bar and ball on downthrown side

Lineament

Large trough

Mare dome

Orientale ring structure—Hachures mark steep face; barbs show steep limb of innermost ring (fig. 1)

Older basin ring (fig. 1)

Dark mantling material

Buried crater outline

Buried Orientale secondary crater outline

Blue mare material (red mare unstippled)

GEOLOGIC SUMMARY

PHYSIOGRAPHIC SETTING

The map area extends from Oceanus Procellarum westward into the terrae of the western limb of the Moon and is dominated by the Orientale basin, a great multiringed impact structure about 1,000 km across. Elevations increase westward across the map from about –2.5 km in Oceanus Procellarum to more than 5 km in the highlands west of Orientale. The terrain is exceedingly rugged outward from the Montes Cordillera around Orientale but becomes increasingly smooth in the outer facies of the ejecta and beyond the ejecta deposits around the basin. Eight large older multiringed basins surround Orientale in this region of the Moon. With the exception of Orientale, only those adjacent to Oceanus Procellarum have their centers filled or partly filled with mare basalt. In the discussions that follow emphasis has been placed upon those geologic units and structures that are associated with the Orien-tale basin. Some of Orientale's more noteworthy features include: (1) the greatest number (four) of clearly distinguishable rings of any basin, (2) the only continuously mappable ejecta blanket around a lunar basin, (3) the greatest number of distinct basin-associated geologic units, (4) the only basin showing impact produced basin floor materials unburied by mare basalts, (5) the only basin showing relict crater outlines within its major ring, (6) the last major ejecta blanket covering a large part of the Moon, (7) the only basin having a central mascon surrounded by a large well-defined negative gravity anomaly.

STRATIGRAPHY

PRE-ORIENTALE ROCK UNITS. The oldest rocks in the region are those associated with pre-Nectarian craters and the probable ejecta from the Humorum basin, shown as hilly and furrowed material. The massifs and high scarps which form the mountainous rings around the Orientale basin are probably in part uplifted prebasin bedrock consisting of interbedded breccias of older ejecta blankets. Undoubtedly, however, the massifs and scarps are overlain by ejecta from the Orientale basin just as the circumbasin massifs of Imbrium and Serenitatis are shown by samples collected during the Apollo 15 and 17 missions to consist of ejecta indigenous to these basins (Wolfe and Reed, 1975). For this reason, we have chosen to map the massifs as part of the Orientale Group and not as prebasin bedrock as in previous mapping practice.

Along the west margin of the map, faint lineations trending northeast are all that remain of the degraded extremities of the Hertzsprung ejecta blanket. The ejecta blanket covers pre-Nectarian crater materials and in turn is overlain by long stringers and lobes of the Hevelius Formation and numerous Orientale secondary craters. The Hertzsprung basin is believed to be younger than the Humorum basin to the east because of the relatively sharp appearance of some of its rings and the common occurrence though somewhat degraded form, of its secondary craters; Humorum secondary craters have not been recognized.

The north-central part of the map area is marked by hummocky to swirly terrain with lineations directed subradially toward the Imbrium basin more than 1,000 km away across Oceanus Procellarum. This unit is mapped as the Fra Mauro Formation as its general characteristics are very similar to those of materials mapped elsewhere as the Fra Mauro at comparable distances from Imbrium. Superposition relations between the Hevelius and Fra Mauro Formations were not found. However, Orientale secondary craters clearly overlie the Imbrium ejecta blanket and thus directly confirm for the first time the previous supposition based on morphology that the Orientale impact was the later event.

Ejecta deposits from most other major basins within and around the map area are no longer identifiable. They probably are included in the Imbrian and Nectarian terra material which covers most of the area. This terra unit is inferred to be made up of a complex multilayered sequence from both large and small cratering events that occurred relatively early in lunar history.

ORIENTALE GROUP. Three major units associated with the Orientale basin are defined and included in the newly-named Orientale Group of Imbrian age (McCauley and others, in preparation). The Orientale Group is an assemblage of all the materials cogenetic with the formation of the basin: the Hevelius, Montes Rook, and Maunder Formations. The Orientale basin is considered its type area.

The Hevelius Formation, the first recognized and named unit (McCauley, 1967), represents that part of the ejecta blanket which lies mostly outside the Montes Cordillera. It is made up of four gradational facies extending successively outward from the basin.

The inner facies is rugged and coarsely lineated with large, elongate, irregular troughs and ridges mostly subradial to the basin center. All but the largest preexisting craters are masked by this unit, which is estimated to be about 3.6 km thick near the Cordillera rim (Moore and others, 1974). Swirly textures and streamlined surface forms have led many workers to conclude that it was deposited as a ground-hugging surface flow.

The transverse facies consists of patches of small ridges generally alined [sic] normal to the main radial lineations of the inner facies. It occurs mostly along the distal walls of prebasin craters and in long depressions such as that northwest of the crater Inghirami. The ridges are probably formed as a result of a rapid decrease in velocity of the surface flow by opposing crater walls and stresses set up by rapid decreases in velocity between the upper and lower parts of flows within depressions.

The outer facies is relatively thin and discontinuous over a large part of its extent. This facies is lineated in places by narrow ridges and grooves radial to the basin but on a much finer scale than the inner facies. Subjacent terrain is readily discernible beneath this part of the blanket. In places the outer facies contains large patches of smooth plains that cover crater floors and irregular depressions. Many of the plains appear to be laterally continuous with the outer facies; others embay and have sharp contacts with this unit or have Orientale secondary craters superimposed on them and thus are respectively either younger or older than the Hevelius Formation. Those that are continuous with the outer facies are included in the Orientale Group whereas the others probably have a variety of origins and ages that span the impact event and have been mapped as a separate unit, plains material. In the west half of the map area, where photographs are particularly poor, the boundary between the inner and outer facies of the Hevelius is locally indeterminate and the outer limit of the formation is not easily defined. The Hevelius is distributed irregularly and somewhat asymmetrically around the basin and has numerous broad lobes like those extending across Schickard and Poynting.

The secondary crater facies consists of numerous chains and clusters of secondary craters within and beyond the mapped extent of the Hevelius Formation. They can be recognized within a zone extending from about 600 km to 2,000 km from the basin center where they commonly occur in clusters and linear chains. Most of the secondary craters within the area covered by the continuous ejecta blanket arc buried to varying degrees. Those that occur within the inner facies of the Hevelius are highly subdued by erosion and burial by the ground surge. Secondary craters in the outer facies, however, have relatively sharp rims and appear to have been only thinly covered by ejecta deposits. Some secondary craters are elongate or overlapping to form narrow sculptured grooves; these were probably formed by low-angle trajectory material or by blocks entrained in the ejecta cloud. Others are nearly circular in outline, suggesting they were produced by low-velocity (less than 2.38 km/sec) fragments impacting the surface at high angles. If a lower limit of 30° from the horizontal is assumed for the impact angle, the equations of Giamboni (1959) yield a minimum flight time of about

10 minutes and a velocity of 1.0 km/sec for ejecta which formed the first recognizable nearly circular craters about 600 km from the basin center. As these secondary craters were later buried by the outrushing ground surge, the average velocity of this debris-laden cloud must not have exceeded 1.0 km/sec and probably was much less. The more distant secondary craters at a range of about 2,000 km were made by ejecta having velocities exceeding 1.5 km/sec, although ejection angles might have varied between about 10 and 50° (Wright and others, 1963).

The Montes Rook Formation was named informally by McCauley (1968b). Its textures, distribution, relative age, and stratigraphic position within the Orientale Group are most important to developing the sequential history and kinematics of basin formation. With some notable exceptions, it is mostly confined to the region between the Montes Cordillera scarp and Montes Rook. It has a blocky to knobby texture and on this basis is divided into two facies: (1) The massif facies consists of large rectilinear blocks and prominent smooth scarps described above (see section entitled “Pre-Orientale Rock Units”); individual blocks are measured in tens to hundreds of kilometers. (2) The knobby facies is made up of more rounded to cone-shaped blocks ranging in size from about 10 km across to the limit of resolution (about 100 m); these are set into a smooth gently rolling matrix. The facies is faintly lineated and, significantly, several ghost craters are visible along its eastern edge; these craters indicate that the original impact cavity did not extend to the knobby facies. Northwest of the crater Schlüter and at several other localities around the basin this facies is draped across the Montes Cordillera scarp or outer ring of the basin. Islands of well-lineated Hevelius Formation occur within the knobby facies and inside the scarp. This facies is analogous to the Alpes Formation (Page, 1970) of the Imbrium basin and has been variously interpreted as fallback, the product of postcratering gravitational collapse, and shock fluidization of prebasin bedrock. The knobby facies of the Montes Rook Formation is now considered an integral part of the Orientale ejecta sequence and is thought to be nearly unmodified by postbasin events, and, as noted above, to lie outside a deep transient cavity that existed during basin formation (McCauley and others, in preparation; Moore and others, 1974). The knobby facies is interpreted as deep-seated material possibly derived from beneath the 60-km lunar seismic discontinuity (McCauley and others, in preparation; Toksöz and others, 1974, Moore and others, 1974). Its superposition on the Hevelius Formation, general lack of radial lineations, and blocky forms, together with some experimental large-scale cratering data (Roddy, 1969, 1973) suggest that it was emplaced late in the cratering sequence and with little radial velocity (Gault and others, 1968). It represents the uppermost part of an overturned flap produced by impact cratering (Shoemaker, 1962).

The innermost unit of the Orientale Group, here named the Maunder Formation after its exposures around the younger crater Maunder in the central part of the basin, lies between the Montes Rook Formation and mare basalt that fills the center of that basin. It has a relatively smooth undulatory surface but with many concentric and radial fissures which produce a wrinkled appearance. The Maunder Formation is gradational with plains units, has a similar albedo, and resembles the materials on the floors of the young lunar craters Tycho and Aristarchus. It is interpreted to consist principally of impact melt formed within the original crater floor. The pattern of the fissures suggests uplift of the floor by isostatic adjustment resulting in normal faulting and extension of the solidified floor material.

POST-ORIENTALE ROCK UNITS. Mare basalts and, locally, plains materials bury or partly bury parts of the Orientale Group, and craters of late Imbrian age and younger are superposed on its various formations. Over most of the region, particularly the western half, Lunar Orbiter photographs are inadequate to allow differentiation between light and dark mare and between plains and light mare materials. However, Zond 8 photographs obtained by Harold Masursky of the U.S. Geological Survey from

C. P. Florensky, V. I. Vernadsky Institute, Moscow, U.S.S.R., taken at very high sun angles clearly show albedo variations associated with these units. They also show rays and bright haloes around craters, thus permitting the identification of Copernican age craters. Color boundaries between red and blue mare basalts are preliminary and highly generalized from the current work by Soderblom. Unlike other areas of the Moon (Soderblom, 1970), there appears to be little correlation between spectral reflectance and albedo in Oceanus Procellarum. Most of the dark mare along the west edge of Oceanus Procellarum is red but in some places it is relatively blue. The mare basalts within the quadrangle range from Imbrian to Eratosthenian in age (Boyce, 1975), and no correlation is evident between age, albedo, and color.

STRUCTURE

The ring structures of the Orientale basin are mapped along their topographic crest lines on the accompanying structural diagram (fig. 1). They are best seen under the low lighting of Orbiter IV medium-resolution pictures, from which most of their characteristics and dimensions have been described. Acquisition of Zond 8 pictures, closer inspection of the Orbiter V data, and geologic mapping around the entirety of the basin reveal: (1) irregularity of crests, (2) a segmented, blocky character to the inner rings that is apparently controlled by a preexisting fracture system, (3) numerous radial and subradial lineaments, and (4) faults that displace or rotate individual ring segments on the order of tens of kilometers. Only the most pronounced of these are shown on figure 1. They appear to be analogous to the tear faults mapped in the walls of many terrestrial craters that developed during the cratering event and are not related to postcrater slumping. The Montes Cordillera ring and the outer and inner Montes Rook rings are generally indistinguishable in the southwestern part of the basin. Here the normal concentric trends of these structures are lost within an enormous array of structured massifs, mapped as one large patch because of the quality of the photographs. The apparent greater dislocation of the massifs and the lack of definition of the rings in this region may be related to obliquity of impact, to preferential crustal weakness along certain azimuths, or to energy asymmetry of the initial transmitted shock wave at impact. The degree of structural deformation observed here and the general asymmetry of the ejecta blanket itself are consistent with a basin formed by a bolide, incident at a moderately oblique angle from the northeast. Regardless, it is now apparent from the above observations that the concentric asymmetry and continuity of the Orientale rings are considerably less than previously thought.

The Maunder Formation, characterized by extension fractures tectonically or thermally induced, also contains numerous gently sloping ridges and domes. Many of the ridges show axial fissures radial or concentric to the basin center. Data from experimental explosion craters (Roddy, 1969, 1973) suggest that these ridges are compressional features formed late in the cratering event by inward motion of material from beneath the crater floor and inner ring.

For geologic and experimental reasons described here and elsewhere (McCauley and others, in preparation), we consider the original rim of the crater at Mare Orientale to lie within the circumference of the Montes Rook. This rim approximates the hinge line around which overturning of the flap and inversion of ejecta occur in terrestrial impact craters and in experimental craters of all sizes. Our mapping shows a maximum possible diameter for the original crater of approximately 450 to 500 km. The inner Montes Rook ring probably represents a circular central peak structure of the type described by Milton and others (1972) and Milton and Roddy (1972). Spacing with regard to the inferred rim crest, texture, and the highly segmented appearance of this ring are consistent with this interpretation. The innermost ring of Mare Orientale has a gentle inward facing scarp that appears to be a structural terrace marking the steep part of the original cavity into which basalt was extruded and later partly withdrawn. This structural terrace may represent a major strength discontinuity in the lunar subsurface (McCauley and others, in preparation).

The Montes Cordillera ring and scarp is a seismic-wave-induced ring fault that formed outside the original crater probably as the result of sequential compressional and tensile stresses followed by mass movement of material toward the basin cavity. A similar ring is observed around experimental explosion craters (Roddy, 1969) and shows that deformation extends well beyond the crater walls. Postcratering slumping along this structure is considered to be a subordinate process and limited to those areas where scarps with bright slopes appear on the photographs (less than 20 percent of the circumference of the Montes Cordillera ring).

Outside the Montes Cordillera ring, concentric faults and grabens persist on a diminished scale mostly visible only as lineaments within the inner facies of the Hevelius Formation (fig. 1). Some concentric features in the area between the craters Shaler and Baade on the south side of the basin appear as troughs and grooves or have bright south-facing scarps antithetic to that of the Montes Cordillera. Radial and subradial systems are pervasive in both the inner and outer facies of the Hevelius Formation. They consist of faults and grabens of tectonic origin as well as grooves and ridges formed by scouring and deposition of the ground surge and by secondary cratering. Structures radial to the basin are more apparent than real as indicated in figure 1. Many of the lineaments are nearly parallel and occur in two broad zones extending across the basin. Within each zone the lineaments trend about N.60° E. and N.50° W., and only those relatively close to the linears extending through the basin center in these directions can be considered radial. In the broad arcs to the north and south of the unidirectional zones radial and subradial lineaments are present. Thus, it seems that an ancestral structural pattern exists around Mare Orientale where basin radial sculpture consisting of fractures and gouges are superimposed on an older regional structural grid. In many places, however, it is difficult to distinguish between tectonic lineaments and those formed by ejecta gouging and scouring. Some criteria which indicate mode of origin have been noted in the study of Imbrium sculpture (Scott, 1972). Evidence of tectonic origin is shown by associations of the following features: (1) variations in apparent relative age of parts of the sculpture, (2) furrows without rims, (3) absence of ballistic shielding—furrows cutting across crater rims, walls, and floors, (4) absence of scalloped edges along troughs, and (5) linear assemblages of nonradial features, especially in directions of the two major grid systems. Ridges within Oceanus Procellarum, for example, generally follow the northwest and northeast trends of structures within the grid zones and are believed to represent extrusions of basalt along fractures produced by tensile stresses (Scott and others, 1975). Many lineaments in the ejecta may be made by material preferentially ejected along azimuths following preexisting structural dislocations. Elastic wave propagation is probably higher in these directions where rock compressibility may be less; possibly this is analogous to higher seismic velocities along rather than across planes of stratification. Roddy (oral commun., 1975) points out that experimental craters in coarsely crystal-line rock have exhibited similar asymmetry in ejecta patterns and elongate rays related to joint systems in the rocks.

TOPOGRAPHIC AND GRAVIMETRIC DATA

Laser altimeter profiles extending westward from the mare in Oceanus Procellarum across the northern part of Mare Orientale and the Montes Cordillera show an elevation difference of 6 km or more. The mountains also rise about 3.5 km above the basin floor between Montes Rook and Montes Cordillera. Supplemental profiles made by G. M. Nakata of the U.S. Geological Survey using a stereo-analytical plotter indicate that the mare in the center of the Orientale basin lies about 2.5 km below the basin floor enclosed by Montes Rook and Cordillera; thus the mare basalt within Orientale may be about the same elevation as that along the west margin of Oceanus Procellarum.

Outside the Cordillera ring, the ejecta blanket has large-scale roughness where in many places slopes of 5 to 10 degrees occur between laser points spaced approximately 30 km apart. The plains-covered floor of the Hertzsprung basin is depressed about 3.5 km below its outer rim and appears to be 1 to 2 km higher than the mare fill within Orientale.

Previous work (Scott, 1974) indicated that the negative gravity anomaly associated with the Orientale basin is about –360 milligals. The conspicuous but areally restricted mascon under the central part of the basin has a total difference in magnitude of about 460 milligals, of which only 100 milligals represents the uncompensated load. These values correspond to a plug of basaltic material having about the same diameter (300 km) as the mare-filled basin center and extending to a depth of approximately 50 km (probably to the mantle). These data have been used (Scott, 1974) to obtain volume estimates of the amount of material ejected from Orientale that are in close agreement with those calculated from basin ejecta (Moore and others, 1974).

Recent gravity studies of the Moon's far side (Ananda, 1975; Ferrari, 1975) show basins in this region to be associated with localized negative anomalies. In particular, and within the map area, Hertzsprung (lat 0°, long 130° W.) and Lorentz (lat 35°N., long 100°W.) show anomalies of about –10 and –50 milligals, respectively. Laser altimeter data available across Hertzsprung show that the volume deficiency of this basin can be approximated by a disk with a diameter of about 500 km and a thickness of 2 km. Calculations using a density value of 3.0 g/cm^3 for the displaced mass yield a theoretical gravity value of -160 milligals for Hertzsprung. It thus appears that about 90 percent of the basin void has been compensated isostatically even though no mare basalt is evident at the surface. The difference, then, between farside and nearside lunar basins is that the latter are overcompensated by basalt flows owing to their lower elevations and, consequently, more favorable hydrostatic position. The Orientale basin has an intermediate location on the west limb between mare and farside terra; this is reflected by its gravity response, a broad low area encircling a central high. Thus the position of a basin in the Moon may affect mascon expression more than the relative age of the basin (Howard, 1970).

HISTORICAL SUMMARY

The west limb region of the Moon consists of highly cratered terra rising 5 km or more above the mare of Oceanus Procellarum and most of the lunar near side. Crustal material in this area of large basins and craters has been redistributed repeatedly by giant impacts. The early historical record of these events is apparently preserved in a complex of interlayered breccias, which may be partly exposed in the walls of the larger craters. Orientale, the last multiringed basin, was formed early in lunar history during the waning stages of high impact flux by a large body probably impacting the surface obliquely from the northeast. Ejecta from this impact was widely scattered over the Moon and appears to form some of the plains materials. Although the major landforms of the Orientale basin were developed instantaneously in geologic terms, isostatic adjustments were more protracted; the accompanying structural dislocations including concentric and radial faults in the floor material may have continued up to the time of mare basalt flooding after basin formation. Subsequent impacts have produced craters generally less than 60 km diameter.

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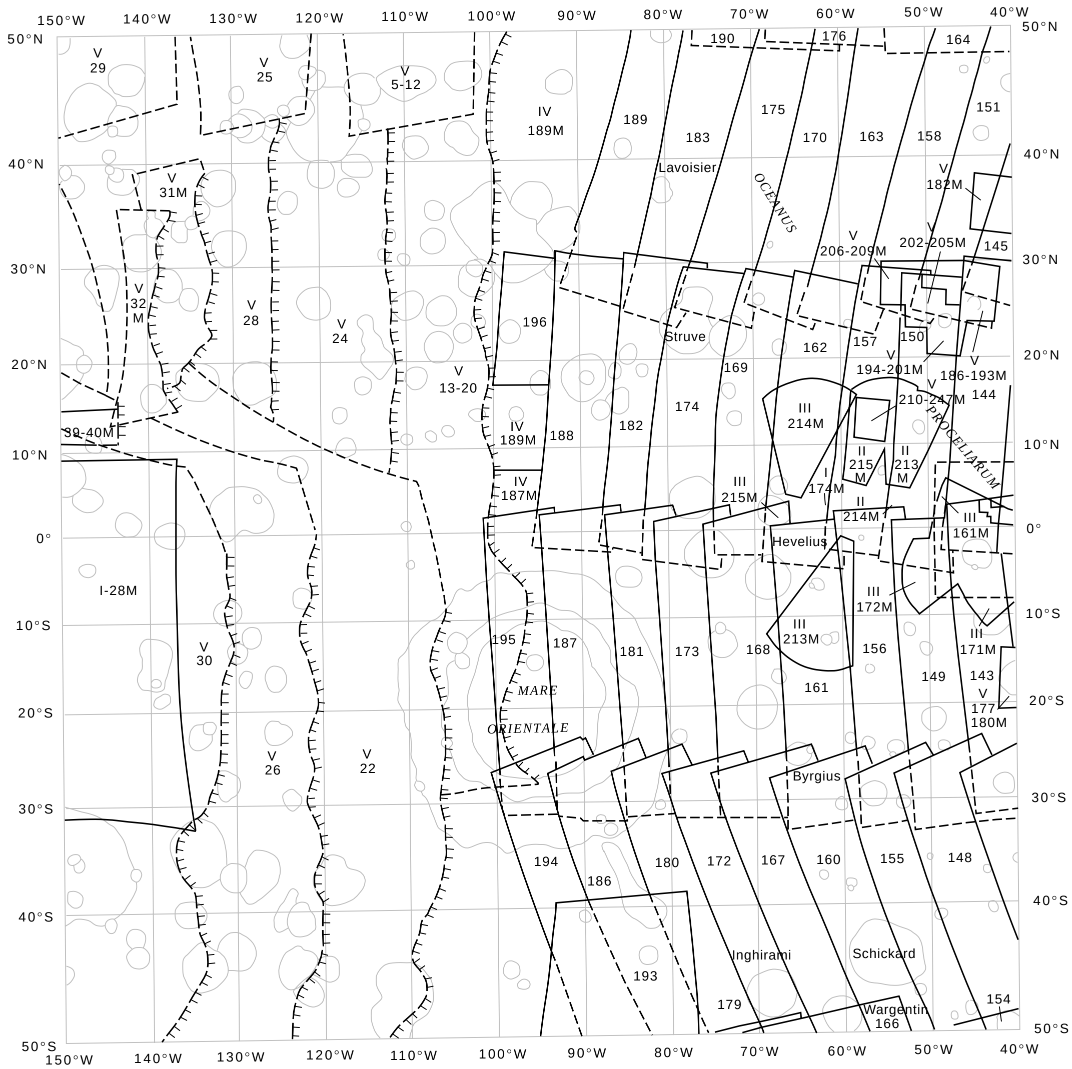
Mapped 1974-1976. Principle data sources; Lunar Orbiter photographs plotted on index map, courtesy of National Aeronautics and Space Administration, and albedo form USSR Zond 8 photographs. Adjoining geologic maps at same scale: farside map by Stuart-Alexander (1978) adjoins west map boundary; nearside map by Wilhelms and McCauley (1971) adjoins and overlaps east map boundary; northside map by Lucchitta (1978) overlaps north of 45° N.; southside map (Wilhelms, et al., 1979) overlaps south of lat 45° S.

Geologic maps at 1:1,000,000 scale entirely or partly within area by Wilshire (1973), McCauley (1973, 1967), Moore (1967), and Scott and Eggleton (1973) work performed on behalf of the National Aeronautics and Space Administration under Contract No. W-13,130.

Shaded-relief base charts, 2d ed., October, 1970, prepared by Defense Mapping Agency, Aerospace Center (formerly Aeronautical Chart and Information Center, U.S. Air Force), St. Louis, MO, 60318. East of long 80° W., Lunar Farside Chart (LMP-2). Some feature names shown on these charts have been deleted here. Names shown are selected from the approved International Astronomical Union (IAU) list of 1970.

FIGURE 1 — Structural lineaments and basin rings

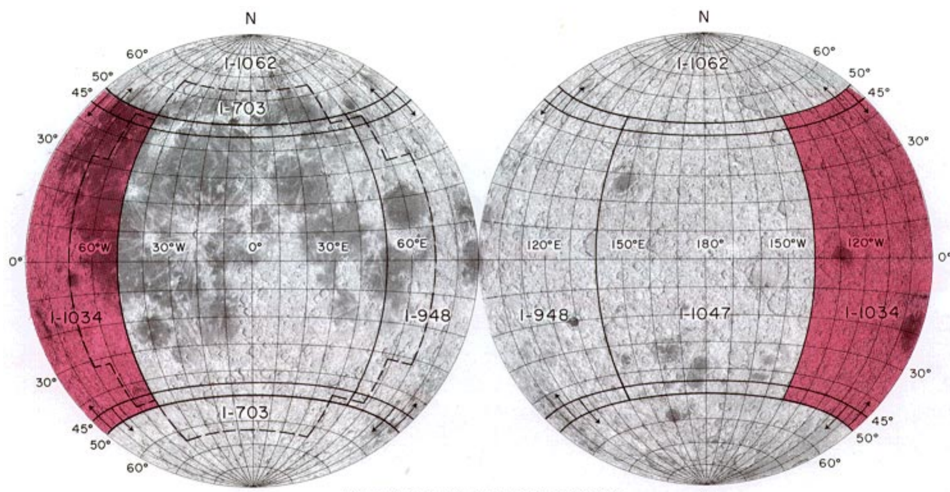


LUNAR ORBITER PHOTO INDEX MAP

LEGEND

Terminator Limit

I 28M - 40M Orbiter I Medium Resolution
II 213M - 215M Orbiter II Medium Resolution
III 161M - 215M Orbiter III Medium Resolution
IV 187M, 189M Orbiter IV Medium Resolution
142 - 196 Orbiter IV High Resolution
V 13 - 30 Orbiter V High Resolution
V 182M - 217M Orbiter V Medium Resolution



INDEX MAP OF THE MOON
The number preceded by I refers to published 1:5,000,000 geologic map

I-703	Geologic map of the Near Side of the Moon (dashed line)
I-948	Geologic map of the East Side of the Moon
I-1034	Geologic map of the West Side of the Moon
I-1047	Geologic map of the Central Far Side of the Moon
I-1062	Geologic map of the North Side of the Moon